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PREDICTION OF HEAT STRAIN, REVISITED 1979-1980,(U)

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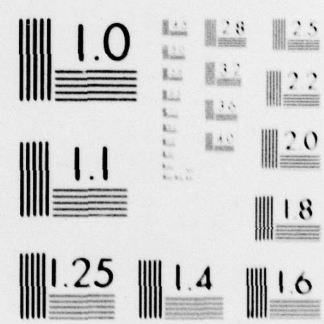

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The original 1972 criteria for a Recommended Standard "Occupational Exposure to Hot Environments" are reviewed. The use of two air motion levels for WBGT is questioned and WGT is suggested as a simpler index for routine work site assessment. The use of body core temperature as a basis for recommendation is questioned (unresponsive and unmeasurable) and heart rate based criteria are suggested. Differences in WBGT criteria based on gender, and emphasis placed on age are questioned; it is suggested that individual fitness, genetically based work capacity, and state of acclimatization are far more relevant although age and

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1. The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Prediction of Heat Strain, Revisited 1979-1980

by

Ralph F. Goldman, Ph.D.

US Army Research Institute of Environmental Medicine

Natick, Massachusetts 01760

"Prediction of Heat Strain Revisited 1979-1980".

Ralph F. Goldman, US Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760

ABSTRACT

The original 1972 criteria for a Recommended Standard "Occupational Exposure to Hot Environments" are reviewed. The use of two air motion levels for WBGT is questioned and WGT is suggested as a simpler index for routine work site assessment. The use of body core temperature as a basis for recommendation is questioned (unresponsive and unmeasurable) and heart rate based criteria are suggested. Differences in WBGT criteria based on gender, and emphasis placed on age are questioned; it is suggested that individual fitness, genetically based work capacity, and state of acclimatization are far more relevant although age and sex trends exist. Acclimatization and hydration recommendations are supported and amplified, but the need for a 4-day reacclimatization after a 9-day break may require further investigation. The emphasis on salt supplementation is seriously challenged. Finally, guidance for work in heat involving wear of protective clothing is suggested.

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It has been almost ten years since the Occupational Safety and Health Act of 1970 emphasized the need for Standards to protect the health of workers exposed to heat. A criteria for a Recommended Standard" Occupational Exposure to Hot Environments" was published by HEW in 1972. The recommendations made at that time included the following:

1. The WBGT index was specified as the environmental metric of choice, with a value above 79°F defined as a hot environment.

2. For sedentary jobs where continuous unimpaired mental performance was required, no employee should be exposed to conditions of 30.5°C for more than 4 hours, 31° for more than 3 hours, 32° for more than 2 hours or 33° for more than 1 hour with exponentially decrementing exposure times as WBGT increased to 43°C at which, in theory, some 15 minutes of exposure was allowable.

3. No employee was to be permitted to work without observation at high heat stress levels; however, "high heat stress levels" were not specifically defined.

4. Different criteria were established for men (time weighted average WBGT 79°F) and women (76°F) as the threshold for concern.

5. The upper limit of employee body core temperature was not to exceed 100.4°F.

6. Unacclimatized employees were to be acclimatized over a period of 6 days, beginning with 50% of the anticipated total work load/time exposure on the first day, followed by 10% daily increments to reach 100% exposure on the sixth day.

7. A break of nine or more consecutive calendar days of leave required a 4 day reacclimatization beginning, again, with 50% of anticipated exposure on the first day, with 20% increments on subsequent days to reach 100% on the 4th day.

8. Absence for 4 consecutive days of illness required a similar 4 day reacclimatization period, as well as "medical permission" to return to the job.

9. A minimum of one break every hour was prescribed "for employees to get water and replacement salt". A minimum of 8 quarts of cool, potable 0.1% salted water (or salt tablets) per man per shift were to be provided, with the water supply never further than 200 ft. from the work station.

Work practices to distribute load over the entire work day, scheduling hottest jobs for the coolest part of the shift, appropriate work/rest regimens to reduce peaks of strain and improve recovery, appropriate protective clothing, equipment and the like were also recommended. Warning signs for areas where WBGT exceeded 86°F, and training programs for the work force were required. Special care was suggested for employees 45 years of age or older. A medical evaluation was specified for personnel who were to be assigned to hot jobs for the first time,

with periodic re-examinations every two years for employees under age 45 and every year for employees 45 years or older. Finally, massive record keeping requirements were imposed, with monitoring requirements specified. This paper will review work during the past 10 years which provides information relevant to some of the proposals incorporated in the original 1972 document, in some cases reinforcing the original recommendations and in others suggesting alteration.

The Environmental Index-WBGT or WGT:

The choice of the WBGT index has never seriously been questioned, based on its demonstrated utility in reducing heat casualties during military training. However, a few comments seem appropriate about the use of this index. First, the 1974 OSHA recommendation specifies different WBGT criterion as a function of air motion; air motion is difficult at best to measure in an industrial setting, and there is no theoretical reason why, if WGBT is appropriately measured, there should be any need whatever for a separate assessment of wind speed. The use of the non-psychrometric wet-bulb lies at the very heart of the applicability of WBGT index to the worker since, the argument is, no one is going to swing the worker by the heels with 100% sweat wetted skin to insure that he receives the same maximum evaporative potential as the conventional "psychrometric" or slung, wet-bulb thermometer.

A second problem with the WBGT is that a number of instruments have appeared on the market for its measurement, some of which use the psychrometric wet-bulb; this is totally inappropriate but some claim to be consonant with OSHA requirements; it would appear that some sort of OSHA certification of WBGT instrumentation will be required.

Third, the classic WBGT instrumentation is expensive, requires obtaining an expensive and hard to find 15.4cm (6") black globe, much of what is commercially available involves requirements for calibration, glass thermometer columns separate or break, requiring replacement of mercury in glass thermometers, etc. A further problem with the WBGT is that the wick must be kept relatively dust free and clean, since erroneous results will be derived if the wick becomes dirty. Finally, the need to measure 3 different temperatures, to perform a mathematical combination, or rely on electronics which do the integration, and to maintain calibration pose additional problems for the worker monitoring the work space stress. Admittedly, for the expert attempting to assess the factors reducing heat stress, the ability to differentiate between low air motion, high ambient humidity, or radiant heat load, provided by measurement of the independent parameters is extremely valuable; however, for the routine monitoring of heat stress at the work place the need to measure 3 separate instruments or 3 separate sensors, and combine them into a single index is troubling.

We have recently investigated in detail the Botsford "botsball", a small, wetted, black globe with a metallic stem thermometer indicating "wet globe temperature", WGT, which we feel offers distinct advantages over the WBGT index. Although allegations have been made that it has not been assessed in an industrial setting, in an outdoor setting, etc., our review of the literature suggests that it has been adequately evaluated indoors and, at least in our study, extensively evaluated outdoors. The WGT appears perhaps to have gained as wide acceptance in heat stress industries as the WBGT. It will be difficult to keep wet in a hot-dry, high

radiant heat load environment. We are also concerned that the black cotton cover is not changeable, may get dirty and is bleached by sunlight. It does provide a different reading than WBGT, but it seems quite clear that the WBGT can be derived by linear translation, if necessary, from the simple equation WBGT = 1.044 WGT - 0.19 with sufficient precision for all practical stress monitoring. Alternatively, we have suggested that for adoption of WGT by the Army, the dial of the WGT thermometer simply be color coded green, yellow, pink and red, to indicate the varying levels of heat stress concern, using the criteria established for the Armed Forces in TB MED 175.

We have recently field tested this instrument with the 82nd Airborne Division for assessment of its use by individuals unskilled in the measurement of heat stress in the field, with favorable results. Although it may take a millenia to get through the bureaucratic maze, my personal conviction is that the ability to simply glance at a dial and assess whether the indicator is in the green, yellow, pink or red zone, using an unbreakable and inexpensive instrument, offers so much to recommend it that the WBGT instrumentation has been surpassed for use in the every day assessment of heat stress at most work sites. This does not deny the importance of assessing the individual parameters when a heat stress situation has been identified in an industrial setting, so that the appropriate corrective measures may be invoked.

The Allowable Exposure:

The curve in the 1972 Recommended Standard presenting the upper limits of exposure for unimpaired mental performance in theory, applies to unacclimatized individuals since no physical work induced heat acclimatization is involved, and is hard to justify from the literature. Acclimatization, at least from the recommended standards developed by the American Commission of Government Industrial Hygienists appears to be equivalent to a 2°C offset in WBGT tolerance criteria, although this recommendation, too, is rather fuzzily derived from the literature. The more usual recommendation within the military, both in this country and abroad, is that if the "Effective or Corrected Effective Temperature" is $>$30°C under hot, wet conditions with low air motion then one has a reasonable presumption that <u>there will be</u> a decrement in performance of cognitive tasks, with a hierarchy of effect ranging from such relatively insensitive operations as addition, manual dexterity and the like, to more easily decremented tasks such as vigilance and decision making. This conclusion is derived from review of a large numer of psychological studies and draws heavily on the earlier review by Wing. Being unaware of any real basis for the time, temperature interaction guidance on continuous unimpaired mental performance specified in the original draft standard, one wonders whether or not a simple recommendation, such as "sedentary jobs with unimpaired mental performance—there will be a decrement in performance when employees are exposed to conditions WBGT 30°C. In addition, a WBGT above 30°C should be is specifically defined as a high heat stress level for a civilian work force.

"Corrected Effective Temperature" roughly corresponds to WBGT

Male-Female Differences:

The differences in criterion for men and women workers were based on a limited number of studies, with subjects of inadequately defined fitness and acclimatization levels. There is no question that an individual with a reduced maximum oxygen uptake will require a greater percentage of his or her available blood flow for work in the heat to serve the working muscles and provide the oxygen needs of the body; therefore, there will be less cardiac output available to transfer heat to the skin for elimination by sweat evaporation. This is clearly shown by studies by Rowell, by Hermanson, and by others. It is also true that individuals who are unacclimatized will have a delayed sweating response, and will sweat less profusely at a given work/heat stress combination than an acclimatized individual; indeed, conditioning of the sweat gland is one of the major incidents in heat acclimatization. Finally, there is no question that lighter subjects doing essentially the same task as heavier subjects, will produce less metabolic heat and therefore will have a reduced need for evaporative cooling in the same environment.

It appears that it is this combination of factors i.e., that females are lighter, are less acclimatized and less fit, that has been misinterpreted to say that females do not tolerate heat stress as well as males. The female is usually less heat acclimatized because in our society "nice girls don't sweat". Feamles are usually less fit because they have, at best, a genetically based, lower maximum oxygen uptake than a male of equivalent fitness; they also tend to be of lower physical fitness classification, because of our culture rather than of any innate need for the average female to be in only fair condition while the average male will be in average condition. There is no arguing that the unacclimatized, unfit female is less tolerant of heat stress than the average, more fit, more acclimatized male. Since physical fitness alone induces roughly the equivalent of the first three days (or over 50%) of the total benefit induced by 6 or 7 day acclimatization to work in heat, fitness is very important. Neither can one aruge that for heavy work in the heat, the female worker, with her genetically based, lower maximum oxygen uptake will not be at a disadvantage compared to a male of the same fitness category. However, most industrial work in our society does not demand that level of sustained hard work. My Institute has completed a series of studies comparing male and female workers in the heat; a major difference between our studies and those reported in the earlier literature is that the females we selected were of good, to above average physical condition, and were carefully heat acclimatized before we compared their responses to those of heat acclimatized males. The results of our studies suggest strongly that under hot-wet conditions, acclimatized females, performing moderately hard work (walking at 3 miles per hour on a level treadmill, which is a level of sustained work unlikely to be experienced in industry) are no worse than and may be slightly better than male workers. Under hot-dry conditions, the females appear to have a statistically significant, but practically meaningless disadvantage. Thus, I would strongly argue that gender is an inappropriate metric for discrimination for heat stress criteria and one which, in our modern American society, is not apt to be accepted by the work force without more justification. A discrimination in criteria for heat stress exposure does exist based on physical fitness and acclimatization to heat; it is recommended that the criterion differentiating males from females, be eliminated in favor of criterion based on fitness and state of heat acclimatization.

The Physiologic Limit - Body Temperature or Heart Rate

The recommendation that the upper limit of employee body core temperature not exceed 100.4°F (38°C) is a troubling one on two counts. First, it is unlikely that employee core body temperature will be measured to insure that it is less than 100.4°F. Second, and even more troubling, is that work physiologists have recognized, ever since the classic 1938 studies of Nielson, that body core temperature is primarily a function of heat production, rather than environment. As expressed in our prediction model, rectal temperature will increase from 37.1°C for an individual at rest (i.e., heat production ¢ 105 watts) by 0.4°C per 100 watts of incremental heat production. Thus, the specification that the upper limit of employee body core temperature should not exceed 38°C (100.4°F) can also be looked at simply as another way of stating that the heat production of the worker should not be much above 300 watts. While it is true that many industrial tasks rarely invoke work levels of 300 watts or more, (and even a very fit worker would be unable to sustain heat production demands for more than 500 watts for more than 2 or 3 hours) it seems that this specification adds little to the recommended standard. It might be better to revert to the recommendation of the old German school, that heart rate during work should not exceed an increase of 30 beats per minute, or adopt the recommndations derived from a number of sources including the Army, Horvath and Raven, and others, that heart rate should not exceed 180 beats per minute for any exposure, 160 per beat for 2 hours, 140 beats per minute for 4 hours, or 120 beats per minute for an 8 hour work day.

Effects of Age:

Heart rate is readily measured and, if instead of using the absolute values of heart rate given above, one references the criterion to the finding that the maximum heart rate of an individual is probably not more than 220 beats per minute minus age in years, it is possible to provide an age adjustment for a recommended upper limit of work/heat demand which could be readily assessed in the field simply by measurement of heart rate by radial pulse. A further advantage of this would be that workers of low physical fitness, and hence greater susceptibility to heat illness, would automatically be identified by their heart rate during work in the heat, it might be much more difficult to identify them by their core temperature.

Effects of Protective Clothing:

Additional difficulties with a body core criterion exist for unique work situations where workers are encapsulated in protective clothing; the number of cases where the toxic nature of the environment is severe enough to require encapsulating protective clothing appears to be increasing with the increase with nuclear industries and the increased recognition of the toxicity of some of our chemical processes. Individuals wearing protective clothing for work in the heat require special precautions. In general, our recommendation is that, as a rule of thumb, the WBGT criterion for individuals so encapsulated be reduced by 10°F for assessing the risk of heat exposure.

If the problem is not the ambient environment, but rather the heat production of the worker, (and the ambient environment is much less important than the heat production of the worker, in encapsulated clothing), as the body fails to be

able to eliminate heat by evaporation of sweat on the skin, skin temperature rises to converge towards rectal temperature. We have reported our findings that collapse can be imminent when core temperature is at relatively modest levels (38.2°C) as skin temperature converges on core temperature; although heart rate is not a totally adequate trigger for alerting to this stress, it is certainly preferable and if the conservative criteria recommended for heart rate above were adopted, then heat exhaustion collapse could be more readily avoided for workers wearing essentially impermeable clothing.

Acclimatization Effects:

The acclimatization recommendation is clearly supported by the extensive studies of heat acclimatization that have been carried out over the last 10 years. Our model predicting the effects of acclimatization, which has been validated in some 15 or 20 different studies over the past years, clearly suggests that full acclimatization can be achieved with 6 to 7 days of work-in-heat exposure; most of the benefits accrue during the first 3 or 4 days. The last 2 days simply represent convergence towards the ultimate, 100% acclimatized condition where no further improvement is to be anticipated; Dassler's studies suggest that it takes 21 days for this "absolutely fully acclimatized" level to be achieved, but the acclimatization achieved in 6 to 7 days (95%?) is adequate for all practical purposes. The additional 0.1°C change in rectal temperature between the 7th and 21st day hardly seems worth a recommendation that acclimatization be continued beyond 5 or 6 days. Two points need amplification; first, our studies clearly indicate that a physically fit individual (of above average condition) starts with a cardiovascular conditioning which represents roughly the equivalent of the first 3 days of heat acclimatization. No special criterion recommendation need be made based on physical fitness from this point of view, but the second finding, which is that roughly two to three percent of even military troops is unable to be acclimatized to severe work in heat stress, may require a recommendation. The presumed reason for this failure to achieve full heat acclimatization is low genetic fitness (i.e., low maximum oxygen uptake) which limits their ability to work for the 100 minute per day sustained period in the heat necessary to fully induce heat acclimatization. It is highly likely that a larger percentage of the civilian population will experience difficulty in acclimatization to work in the heat. Thus, some criteria for identifying those individuals with low maximum oxygen uptake perhaps ought to be established, as a screen, to carefully identify those individuals who presumably, even with careful acclimatization exposures, lack the potential for the development of full acclimatization for severe work in heat stress jobs. Such individuals should function quite well under conditions of low physical work demands and modest heat stress, but represent an undue risk, which apparently will not be adequately compensated for by heat acclimatization, for heavy jobs in more severe heat.

Loss and Reinduction of Heat Acclimatization:

The recommendation that a break of nine or more consecutive calendar days of leave requires a four day reacclimatization is not consonant with our findings. Our findings suggest that, once heat acclimatization is well established in a fit young population, the rate of decay is much slower and reinduction much faster, than implied by the original draft requirement. While this may not be equally

relevant for an older or less fit work force, I believe this needs additional research before any firm statement should be made that will require four days of reduced productivity after a nine consecutive day leave period.

A similiar concern is the basis for the 4 day reacclimatization period required after an absence of 4 consecutive days of illness, particularly with "sick leave" in our civilian work force as liberally interpreted as it is? It may be too complicated to be more specific, but I would argue that workers returning from such "illness" will be quite apt to pace themselves sufficiently as to not require a reacclimatization, or that one or two days should suffice. Of course, much depends on the nature of the illness; perhaps the recommendation should not be for any mandated reacclimatization schedule, but for a madatory review by the plant or patient's personal physician, with his recommendation required in writing.

Water Requirements:

The importance of adequate hydration has received increased emphasis over the last 10 years. Our model for the effects of dehydration supports Ladell's assertion, from the 1940's, that the body has one to two liters of extra fluid "sloshing around" which can be lost without any real decrement in performance; i.e., a 1 to 2% dehydration may produce little or no decrement. However, every additional percent dehydration (for a 70kg man, a body water/weight loss of 700 grams induced by heat during the work shift represents a 1% dehydration) appears to accelerate the rate of rise of body temperature by roughly 6%. Within the feasible limit for functional performance with dehydration, which we feel is about a 5% dehydration, there appears to be no alteration in the ultimate core temperature the body achieves for work in the heat, even though the rate of rise is markedly accelerated by dehydration. Thus, since the body has sustainable sweat capacity of about 1 liter an hour, the recommendation for a minimum of 8 quarts of cool potable water should receive as much emphasis as possible. Studies by the military, of work in the heat clearly indicate that thirst is an inadequate stimulus to avoid dehydration. It was only when the participants in military maneuvers were weighed during their rest breaks and required to drink back the water lost as sweat during work, that their performance in desert operations was minimally degraded compared with performance when the troops were given water ad lib. Encouraging water intake, by scheduled water (ice tea, etc.?) breaks would help alleviate the effects of severe heat stress.

Salt Requirements:

The recommendation that the potable water be 0.1% salted, or that salt tablets be used, is in distinct conflict with more recent research findings. The recommendation for salt is an old one. It arose from the occurrance of heat cramps in some workers during the first few days of heavy physical work in the heat, probably when they were not eating adequately because appetite was reduced. The average American diet contains an excess of NaCl as is, and there is a growing recognition that some portion of our National problem of hypertension is probably associated with excessive intake of salt. The body's mechanisms for acclimatization include an aldosterone turn on which results in the production of a much more dilute sweat and therefore conservation of body salt. Individuals taking supplemental salt lack this conservation mechanism because there is no need for its induction. In addition, studies by Dassler strongly suggest that development of

other facets of heat acclimatization are delayed by supplementary salt ingestion. Since, if heat cramps occur, they are readily and almost instantaneously reversed by administration of salted water at that time, the current military guides recommend against salt tablets or salted water. It is strongly recommended that this element of the original draft standard be reconsidered.

Effects of Age:

As indicated above, there is support for the argument that older employees may be more at risk than younger ones, based on the classic, physiological evidence that maximum oxygen uptake and maximum heart rate fall with age. However, again in modern America, using age as a criterion is minimally socially acceptable; it seems preferable to treat all employees equally and screen for physical fitness and work capability. Recommendations as to placement in hot jobs and reduction of heat stress exposure should be based on the individual's physiological responses, rather than on arbitrary discrimination based on age and sex.

Shutdown versus Work Practises:

In the current political climate of jobs, economics, management and labor problems it appears socially unacceptable to mandate shutdowns of industries, or work areas, based on arbitrary assignments of a WBGT index. The work practices recommendations proferred by the American Commission of Government Industrial Hygienists where, at given levels of heat stress, work to rest ratios are altered from 100% work, to 75% work, with 25% rest, 50% work rest ratios and, ultimately, 75%/25% work would accomplish two things; it would allow the worker to remain on the job and the industry to maintain some productivity for those days when conditions become excessive in some industries; it would also convince industry of the economic advantages of conditioning the environment, based on experience over the work year, rather than impose arbitrary, mandated standards which will cost industry production and worker pay.

In summary, research on the problems of work in the heat, carried out over the last 10 years, provide support for some elements of the original draft proposal and call into question other elements. It is recommended that the current revision of a Recommended Standard "Occupational Exposure to Hot Environments" consider the points raised above, in deriving a new standard for the 1980's. Perhaps it should also consider the advantages of a less mandatory, perhaps more rational Standard which does not shut down industry and cost jobs but leads to a recognition by both management and labor, of the benefits of altering the heat stress in the work space.